RI 8701

Bureau of Mines Report of Investigations/1982

NEWARK PUBLIC LIBRARY

OCT 6 1982

U. S. GOVT. PUBS.
DEPOSITORY 376

A Case History of a Major Rock Burst

By Fred Leighton

UNITED STATES DEPARTMENT OF THE INTERIOR

I 28.23:

Report of Investigations 8701

A Case History of a Major Rock Burst

By Fred Leighton

UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary

BUREAU OF MINES
Robert C. Horton, Director

This publication has been cataloged as follows:

Leighton, Fred

A case history of a major rock burst.

(Report of investigations / United States Department of the Interior, Bureau of Mines ; 8701)

Bibliography: p. 14.

Supt. of Docs. no.: I 28.23:8701.

1. Rock bursts. 2. Pillaring (Mining). I. Title. II. Series: Report of investigations (United States. Bureau of Mines) ; 8701.

TN23.U43 [TN317] 622s [622'.8] 82-600070 AACR2

CONTENTS

	Page
Abstract	1
Introduction	2
Acknowledgments	3
Experimental procedure	3
Stress change	6
Displacement	8
Microseismic activity	10
Summary of pillar reactions	12
Conclusions	13
References	14

ILLUSTRATIONS

1.	Study area configuration, Galena Mine	4
2.	Vibrating wire stress meter (VWSM) positions in study area	5
3.	Displacement measurement array (closure net) in drift above pillar	5
4.	Geophone positions in and around study area	6
5.	Data from VWSM array	7
6.	Data from displacement measuring array, 1979	9
7.	Microseismic noise rate, May 1978 through May 1979	10
8.	Rock noise location data preceding March 22, 1979, burst	11
9.	Rock noise locations and rock noise rates preceding May 24, 1979, burst	12

A CASE HISTORY OF A MAJOR ROCK BURST

By Fred Leighton [1]

ABSTRACT

The Bureau of Mines monitored a rock-burst-prone pillar in a metallic ore vein, up to and through failure, to measure its reactions to increasing loads, as it was mined. Three parameters were monitored: the stress changes at chosen points within the pillar, the displacement characteristics of the drift above the pillar, and the microseismic activity in and around the pillar. In descending order of effectiveness, the microseismic technique, vibrating wire stress measurements, and displacement measurements reflected the pillar reactions, and all showed good correlation to one another. A major rock burst in the pillar, which destroyed about 100 feet of drift above the pillar, occurred at the end of this study. This burst was preceded by a large anomaly in the microseismic activity in the failure area.

[1]Supervisory mining engineer, Denver Research Center, Bureau of Mines, Denver, Colo.

INTRODUCTION

The Bureau of Mines and the American Smelting and Refining Co. have, for many years, maintained a memorandum of agreement for cooperation in studying the problem of rock bursts in the deep silver mines of the Coeur D'Alene mining district in north Idaho. Rock bursts, which are sudden and sometimes catastrophic failures of a portion of the mine structure, occur with little or no warning and constitute a serious problem both to the safety of mine personnel and to mine production.

The major thrusts of this work have been (1) to develop reliable microseismic techniques to precisely delineate rockburst areas prior to failure and (2) to determine how best to assess the stability of each probable failure area to insure that no personnel are present during failure or that failure control methods such as destressing can be used to avoid or minimize the effects of bursting.

The work has shown that the changing stress conditions that cause rock bursts also cause rock noises, which can be detected and analyzed using microseismic techniques. The source location of individual rock noises can be accurately calculated in three-dimensional space (7-8).[2] Each individual rock noise source can then be plotted on mine maps to delineate potential failure areas, and the rate at which rock noises are generated from each mining area can be analyzed to assess the stability of that area (3, 5-6). Experience has shown that, many times, both when and where rock bursts are going to occur can be determined from microseismic monitoring techniques.

This study also pointed out the need for ways to control or completely avoid rock bursts. A study of destressing by explosives was undertaken, and the method was found to be effective (1-2, 4).

[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Continued use and research of these methods have shown that they are certainly useful and effective but rely heavily on experience and are not yet totally reliable. Although most rock-burst areas are delineated prior to failure, some bursts occur unexpectedly. Occasionally, an apparent microseismic warning is not accompanied by a burst. And, while destressing has been shown to be effective in dealing with localized problems of pillar bursting, the destressing technique and overall effects of destressing on the remaining parts of the structure are not understood. There are indications that the stress transfer associated with destressing may cause problems in other areas (6). For these reasons, research into the use of microseismic techniques and destressing methods has continued.

The main object of the Bureau's ongoing study of rock bursts is to improve microseismic techniques to a totally reliable and complete method incorporating state-of-the-art equipment, improved data analysis techniques, and failure control methods.

To reach this goal, knowledge of the following two aspects of rock-burst failures and control methods is required.

1. It is difficult to distinguish between rock-noise anomalies that are associated with normal structural adjustments and those that are associated with failure areas. Research has been initiated using modern methods of geophone deployment (9) and signal analysis to determine if signal characteristics of rock noises from failure areas are different from those from other areas and, thus, can be separated from background noise. These methods would decrease data analysis problems and allow analysis of failure area data in greater detail.

2. To maximize the efficiency of using destressing techniques for rock-burst control, the mechanics of destressing must be better understood, and the

effects of destressing one area on the remainder of the structure must be defined. This knowledge will provide for maximum effectiveness of destressing with minimum adverse effects on nearby mining areas.

As part of the Bureau's effort to better understand destressing and its effects, several burst-prone stopes in proximity to one another were chosen for study, and a microseismic system was installed to monitor this entire area simultaneously. One stope at the Galena Mine was chosen for detailed study using other methods as well. Although this stope was not destressed because of difficulty in drilling the long holes required, some interesting pillar reactions were observed, and a good history of the pillar up to and through failure was obtained. That history is the subject of this report.

ACKNOWLEDGMENTS

The author wishes to express his appreciation for the continued support and cooperation of the management and staff of the American Smelting and Refining Co.'s Galena Mine, Wallace, Idaho. A special acknowledgment is made of the effort and dedication of Clinton Sines, the resident Bureau of Mines technician at the mine site, whose diligence provided the data from which this paper was written.

EXPERIMENTAL PROCEDURE

The aim of this study was to observe the reactions of a burst-prone pillar to the mining process, as well as to observe the destressing of the pillar, which was anticipated to be necessary as mining neared completion. For this purpose, the stope area between 43-279 and 43-284 raises (RS) in the east end of the Galena Mine, Wallace, Idaho was chosen.

Figure 1 shows this stoping area. The stope is about 300 feet in height, 220 feet in length, and about 10 feet in width. The mining method used was a horizontal, overhand cut-and-fill method. Note the presence of a ventilation "big-hole," a 48-inch-diameter borehole, running through the stope near the 284 raise.

It was felt that the behavior of the pillar could be adequately defined by monitoring the following three parameters: (1) the stress changes in and around the pillar, (2) the displacement characteristics in the drift above the pillar, and (3) the microseismic activity in and near the pillar.

Past experience had indicated that pillar destressing, which reduces the support characteristics of the pillar itself, resulted in increased stresses in the mine structure around the pillar. To assess this load transferral and the changing stress conditions within the pillar during mining, vibrating wire stress meters (VWSM) were installed in and near the pillar as shown in figure 2. Readings from each gage in this array were taken on a daily or near-daily basis except during short periods of readout equipment failure.

Past experience also showed that closure measurements in the openings around the pillar could provide information on how the pillar was being loaded and where the pillar was "stiff" or "soft" in its response to the applied loads along its length. To monitor these displacements, extensometer pins were set in the rib on each side of the drift above the pillar, at approximately 20-foot spacings, as shown in figure 3. These stations were read with a dial gage extensometer on a weekly or biweekly basis, except when pillar reactions indicated a need for more frequent readings.

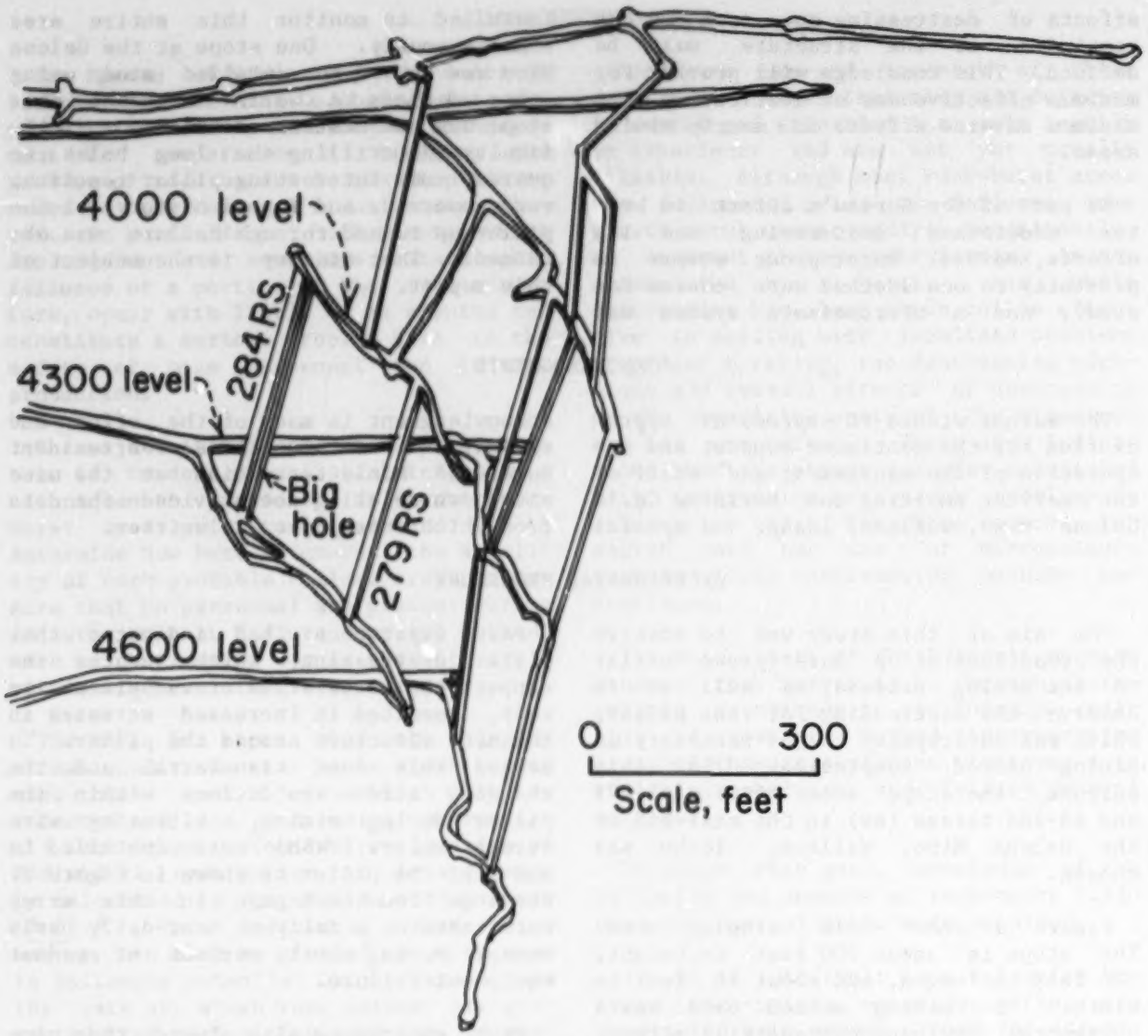

FIGURE 1. - Study area configuration, Galena Mine.

Finally, a microseismic system was used to monitor the entire area in and around the stope, to assess changing stress conditions and the locations and stability of potential rock-burst zones within the area. Geophones were positioned throughout the area as shown in figure 4, to provide precise areawide coverage. Data from this array were recorded and analyzed on an around-the-clock basis, with only minor interruptions throughout the entire period of this study.

Data from these systems were comprised of only background information until May 1978. The data obtained from May 1978 until May 1979, when a major burst occurred in the pillar, are the basis for this report.

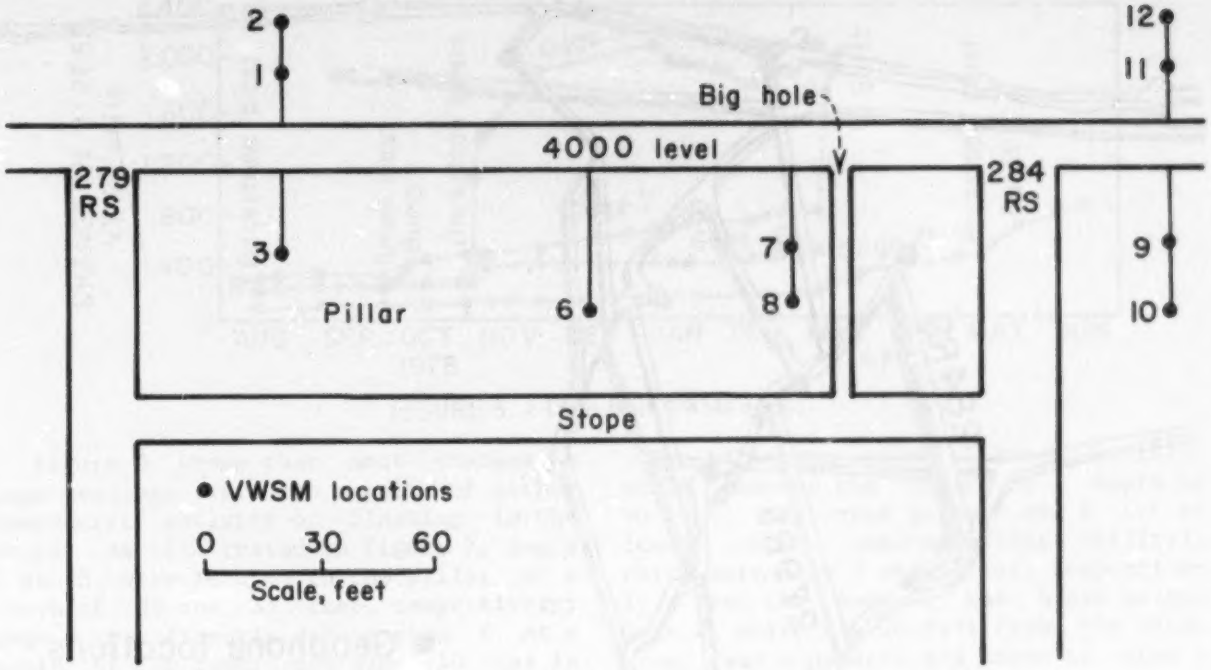

FIGURE 2. - Vibrating wire stress meter (VWSM) positions in study area.

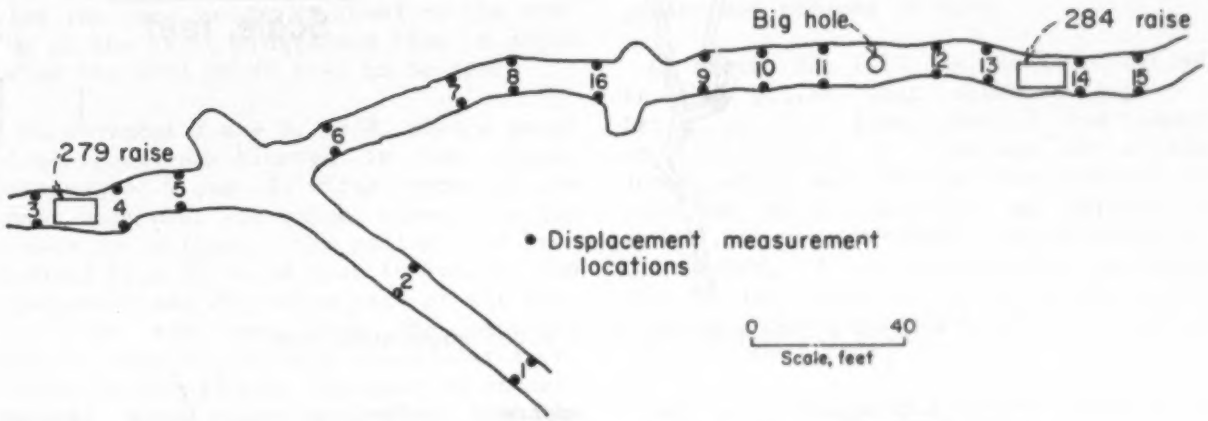

FIGURE 3. - Displacement measurement array (closure net) in drift above pillar.

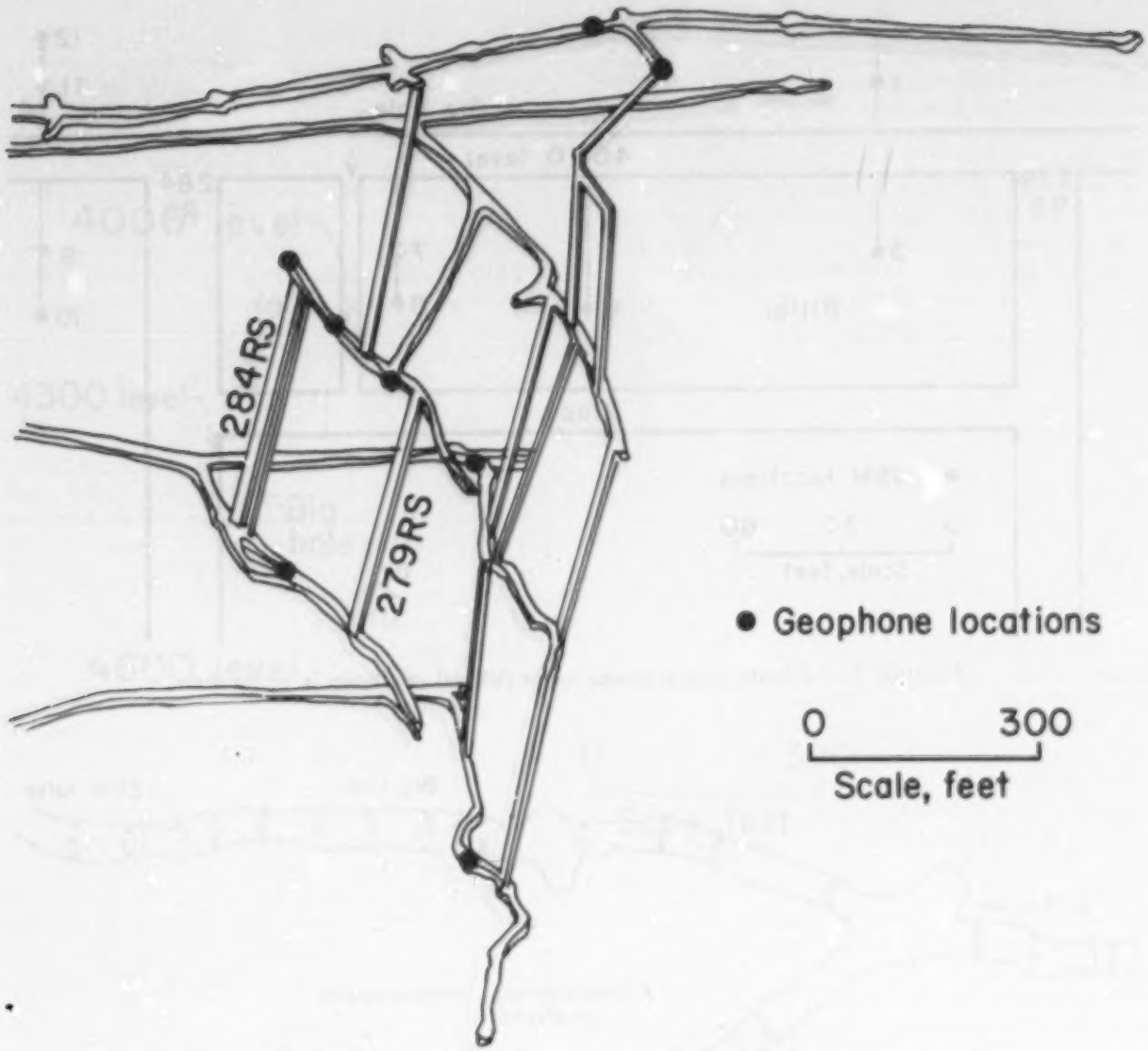

FIGURE 4. - Geophone positions in and around study area.

Stress Change

A total of 12 VWSM gages were installed during this study. Of those 12, 2 became unusable early in the study when their readout wires were lost down the big hole and proved to be unrecoverable. A few, as will be seen in the data, became unusable when blasting during mining occurred very close to their location (within approximately 3 feet). Others were lost at various times because of mining or the apparent unloading of their loading wedges immediately following blasting. However, seven gages worked sufficiently well to provide the information sought from this study. The results from four representative gages are shown in figure 5. In this figure, the stress increases are qualitative, and only the increases at each gage location are shown; that is, the data are not meant to imply that the initial stress at each location was the same.

READEX FICHE best copy available

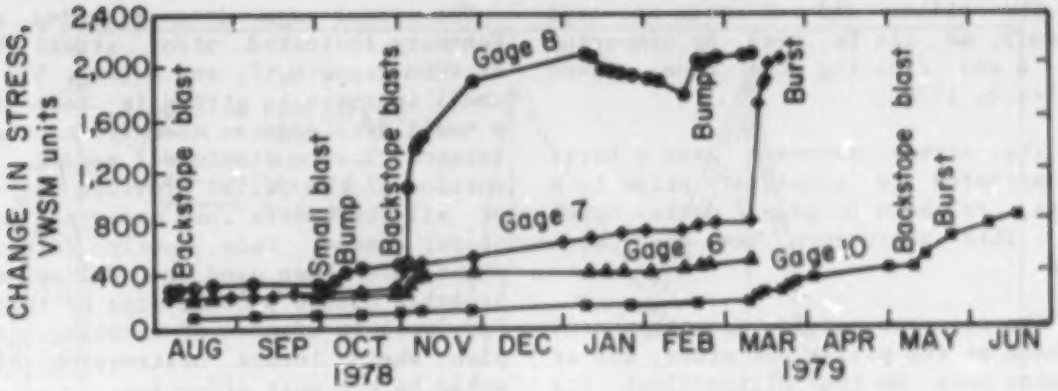

FIGURE 5. - Data from VWSM array.

Figure 5 shows that most changes in gage readings were the result of either bump-burst activity or blasting in the stope. As illustrated in figure 2, gages 6 and 8 were located in the pillar at a depth of 38 and 35 feet, respectively; gage 7 was directly above gage 8 at a depth of 20 feet; and gage 10 was in solid ground outside the stoping area.

During the period May 1978 through September 1978, all gages showed a very slow increase in stress level as the mining of the stope progressed from a depth below the sill of 70 feet to 56 feet.

On November 2 and 3, 1978, when a backstope round was blasted in the stope, both gages 7 and 8, which were in the same hole near 284 raise, showed an increase in stress. The pillar had been reduced from 56 to 48 feet in depth, and apparently the 284 raise side of the pillar took more load than the opposite side. Gage 10, outside the pillar area, showed no significant increase in stress. Gage 8, which was only 15 feet from the new stope opening, showed the greatest increase in stress.

During the period November 3, 1978, to March 9, 1979, gages 6, 7, and 10 showed only moderate increases. Gage 8 appeared to show a decrease in the stress level in its area, followed by a return to its past stress levels. This anomaly in the data from gage 8 preceded a small burst or bump in the area, but no conclusions are drawn from that fact.

The backstope round of March 9, 1979, which reduced the pillar to a depth of 40 feet, destroyed gages 6 and 8 (or at least their load-measuring ability), which were only 2 and 5 feet, respectively, from the ends of the blast holes. Gage 7, which was 20 feet from the blast area, was undamaged and began to show a sharp increase in stress in its area. Gage 10 began to show an increase, indicating that the area outside the stope was beginning to take load as the stope pillar was reduced in size.

On March 22, 1979, a burst occurred in the pillar that disabled gage 7. Prior to its loss, gage 7 had shown an acceleration in increase of stress level, which may indicate that failure is preceded by accelerated, as opposed to steady, stress increase. As a result of this burst, which undoubtedly weakened the pillar, gage 10 reflected increased loading and an increased rate of loading outside the stoping area.

Several conclusions can be drawn from these data.

1. Most of the VWSM functioned about as well as was expected, with most gages lost to nearby blasting over the course of the study.

2. Stresses at a point within the pillar did not seem to increase dramatically until the stope boundary was within about 20 feet of that point, as evidenced by both gages 7 and 8.

3. The pillar did not seem to load uniformly, as can be seen by comparing gages 6 and 8 during the time around November 2, 1978.

4. The stress increase near a burst area appeared to accelerate prior to a failure, as shown by gage 7 during March 1979. This phenomenon has been seen before.

5. The stresses outside the stope area increased as the pillar was mined, and at a faster rate as the pillar lost its load-carrying capability. This is important in determining the effects that destressing a pillar has on the remaining structure.

6. Although they are not shown in figure 5, gages 11 and 12, above and outside the stoping area, did not indicate more than a minimal increase in stress as the pillar was mined and finally burst.

Displacement

The displacement array positioned in the drift above the stope pillar was intended to serve a dual purpose: (1) to monitor drift closure and pillar deformations resulting from stress buildup as a function of mining and (2) to determine closure characteristics (assumed here to reflect "softening" in the pillar) along the length of the pillar, in order to examine the uniformity and effectiveness of destressing by explosives. In the first case, it was assumed that displacements were related to the strain accompanying increased loading on the pillar; in the second case, it was assumed that closures would reflect deformation in the pillar when the pillar was broken and "softened" as a result of destressing.

Figure 6 shows the closures measured along the drift just prior to, during, and after the burst sequence that began in February and ended in the major burst of May 24, 1979.

The stress-gage data recorded during February indicated minor stress changes at VWSM gages 6, 7, and 8 (fig. 5). This small increase in stress is reflected as a small displacement anomaly in the area between closure stations 7 and 12. This portion of the pillar provided the origin of all the bursts that occurred in this stope; hence, this early information might have been used to delineate the probable future problem area of this pillar, well in advance of bursting, and to plan where future destressing efforts would be the most effective.

The burst of March 22, 1979, which was preceded by several days of rapid stress increase at VWSM gage 7, was not preceded by significant information at closure station 9, in the same area. This stress increase without deformation indicates a "stiff" area in the pillar. Such areas have long been considered to offer the capacity to store energy for release in the form of rock bursts. A rapid stress increase without deformation could thus be important in terms of stability studies.

The burst of March 22 ended the effectiveness of the VWSM stress-measurement array and resulted in a large displacement or apparent "softening" of the pillar in the area of closure stations 10 and 11. Note the anomalous displacement at station 9, between 8 and 10. This anomaly is important because the area below stations 10 and 11 did not burst again, but the area between stations 8 and 9 experienced a minor burst on May 11, 1979, and the major burst of May 24, 1979.

On May 11, 1979, a backstope round was blasted in the pillar, which resulted in a burst below station 8. Note the large displacement at station 8 and the small displacement at stations 7 and 9. This again indicates the presence of a "stiff" area in the pillar.

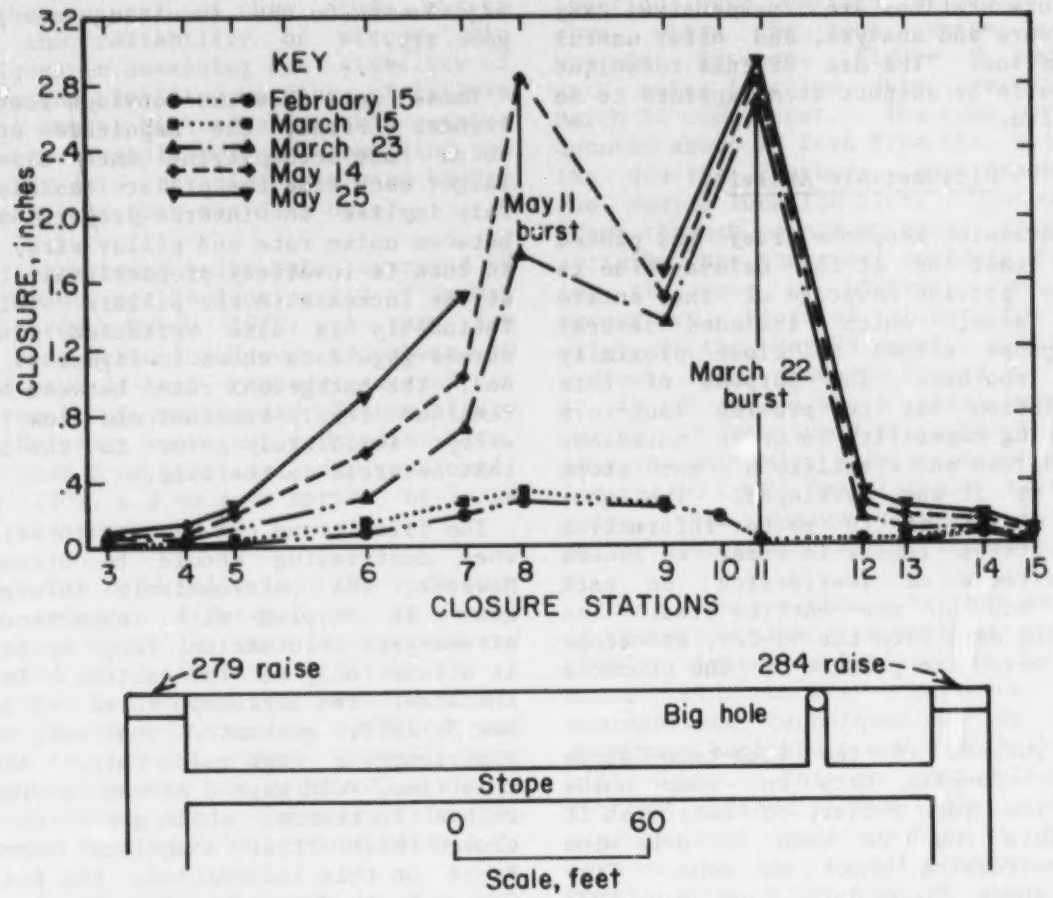

FIGURE 6. - Data from displacement measuring array, 1979. (Discontinuities in data at stations 8 and 10 were due to loss of reference pins during bursting.)

On May 24, 1979, a major burst occurred between stations 8 and 9, which destroyed that portion of the drift and station 8. Station 9 again showed only a small closure, indicating the probability of a "stiff" area yet remaining in the pillar. At the time of this writing, that area has just been mined through, using an end-bite mining technique, and some minor bumping has occurred. Microseismic activity is somewhat higher than usual, even though it has been about 22 months since previous mining there. After that length of time, it might have been assumed the pillar had had time to adjust to the stresses in the area.

The results from this portion of the study indicate the following:

1. Stress measurements (VWSM) and displacement measurements are related and reflect similar information. However, when "stiff" pillar areas are involved early in the mining process, displacement readings may not show them, as was the case preceding the March 22, 1979, burst.

2. As the pillar stoping nears completion and the remaining pillar begins to "soften" in some areas, contrasting "stiff" areas may be observed from closure measurements.

3. Should destressing be used, displacement measurements will probably reveal "stiff" areas, or areas along the length of the pillar where destressing was ineffective. These areas could then be destressed again prior to mining.

Closure stations are inexpensive, easy to measure and analyze, and offer useful information. The use of this technique in trouble or suspect areas appears to be justified.

Microseismic Activity

An areawide geophone array was placed in the east end of the Galena Mine in 1977 to provide coverage of that entire mining area, which included several burst-prone stopes in close proximity to one another. The purpose of this installation was to provide long-term monitoring capability in order to assess the progress and stability of each stope pillar as it was developed. The geophones were also to gather information from destress rounds in order to assess the effects of destressing on each pillar and on the entire area. The following data from the 43-279, 284 stope pillar were the product of the geophone array.

One purpose of the long-term study was to compile data on rock noise rates from each pillar, to establish if these data could be used to determine when destressing should be done. Figure 7 shows these data from May 1978 through May 1979. The stope was being mined by the backstope method of overhand cut-and-fill mining, which requires blasting during only a short period during each total cut cycle. Hence, the plots of rock noise rates show long periods of background or naturally occurring rock noise during cleanout and sand-filling times, with occasional high rates of rock noise, which resulted from blasting and the structural adjustment to the resulting new pillar geometry.

These data show two obvious long-term trends. First, the magnitude of the noise rate accompanying each blast was larger each time the pillar was blasted. This implies an inverse proportionality between noise rate and pillar size, which in turn is inversely proportional to the stress increase in the pillar. This relationship is also reflected in the stress-gage data shown in figure 5. Second, the background rate between blasts remained fairly constant and low level, except immediately prior to the bursts that occurred in the area.

The first trend can be used to estimate when destressing should be attempted. However, the microseismic information must be coupled with experience or stress-gage information, for, by itself, it offers only an indication. In this instance, the backstope round of November 3, 1978, generated what was, in our experience, a high noise rate. Also at this time, VWSM gage 8 showed a dramatic change in stress, while gages 6 and 7 showed their first anomalous reaction. Based on this information, the decision was made to destress this pillar. However, it was found that the pillar was somewhat jointed and that sufficient destress holes could not be drilled; therefore, mining recommenced without destressing of the pillar. The burst following the next backstope round in March 1979 was evidence that the decision to destress the pillar had been made at the proper time. Hence, rock noise rates are of great value in determining when to destress a pillar.

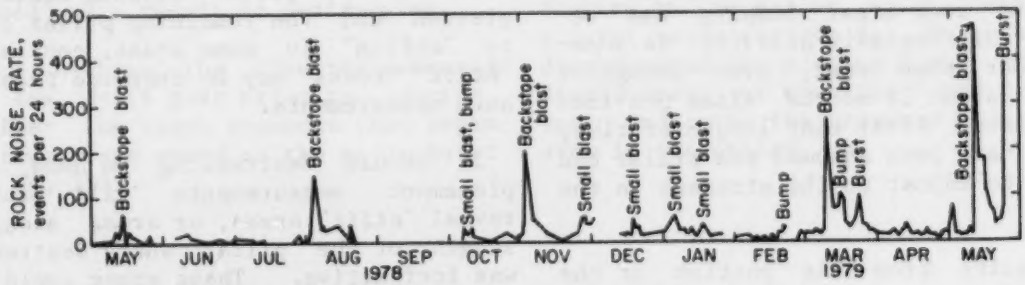

FIGURE 7. - Microseismic noise rate, May 1978 through May 1979.

Another purpose of this study was to check the reliability of microseismic techniques in assessing the stability of an area and providing warning of failure in that area. Historically, this warning has been accomplished by compiling and analyzing data on noise rate and source location, and that was done here.

The background noise rate averaged 10 to 20 events per 24-hour period from May 1978 through March 1979. A very few rates over this level--up to about 50 counts per 24-hour period--occurred as the result of small-scale cleanup blasting. No truly anomalous rock noise data, other than from blasting, occurred until March 1979, and no rock bursts or large bumps were recorded.

The noise rate following the backstope round on March 3 decayed as it should have until March 12, when it reversed and increased until the bump on March 15, at which time it resumed its downward trend. On March 19, it again reversed and climbed to about 5 times normal background noise rate by March 22, when a rock burst occurred. The noise rate then decreased to normal background rates.

This same type of cycle in the rock noise rate was observed after the backstope blast of May 11, 1979. The rock noise rate began a normal after-blast decay, with a slight reversal on May 13 and a bump on May 15. The noise rate decrease then resumed, followed by another reversal on May 20. The reversal culminated in a major rock burst on May 24, 1979.

These examples show the merits of the analysis technique for rock noise rate. In this instance, the technique allowed daily assessment of the stability of the pillar over a year's time and was able to provide warning of impending failure.

In addition to the information on daily rock noise rate, plots of rock noise location were compiled by computer to show where the rock noise activity was most intense. Figure 8 shows the rock noise location data preceding the March 22 rock burst. The rock burst was located about 10 feet from the center of the density contours superimposed on the source location plot. Contours are drawn through points of equal rock noise activity, the innermost contours enveloping the area of highest rock noise occurrence. Plots of the data for 5 days prior to the May 24 burst, without the contours, are shown in figure 9. While it is not known where this burst occurred, it is assumed it again initiated near the big hole, with a second failure located 50 to 75 feet farther toward 279 raise. The damage observed above the pillar also supports this interpretation.

These examples show a further advantage of the microseismic technique: the location of impending failure can be determined prior to its occurrence. Thus, microseismic techniques can be used to determine both where and when rock bursts will occur. This is particularly true for the typical pillar burst, which is also the most dangerous type of burst to persons in the working areas. Those bursts that occur without warning are most commonly those that occur outside of the working area.

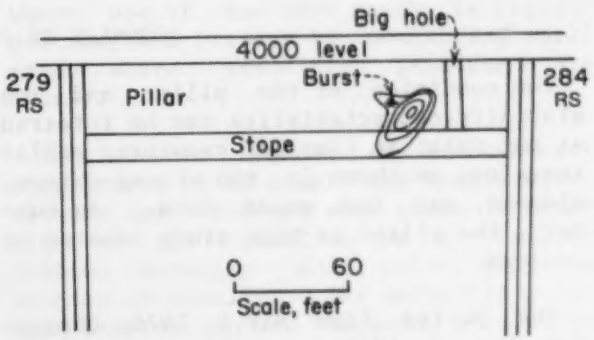

FIGURE 8. - Rock noise location data preceding March 22, 1979, burst. Greatest noise density was at center of contour.

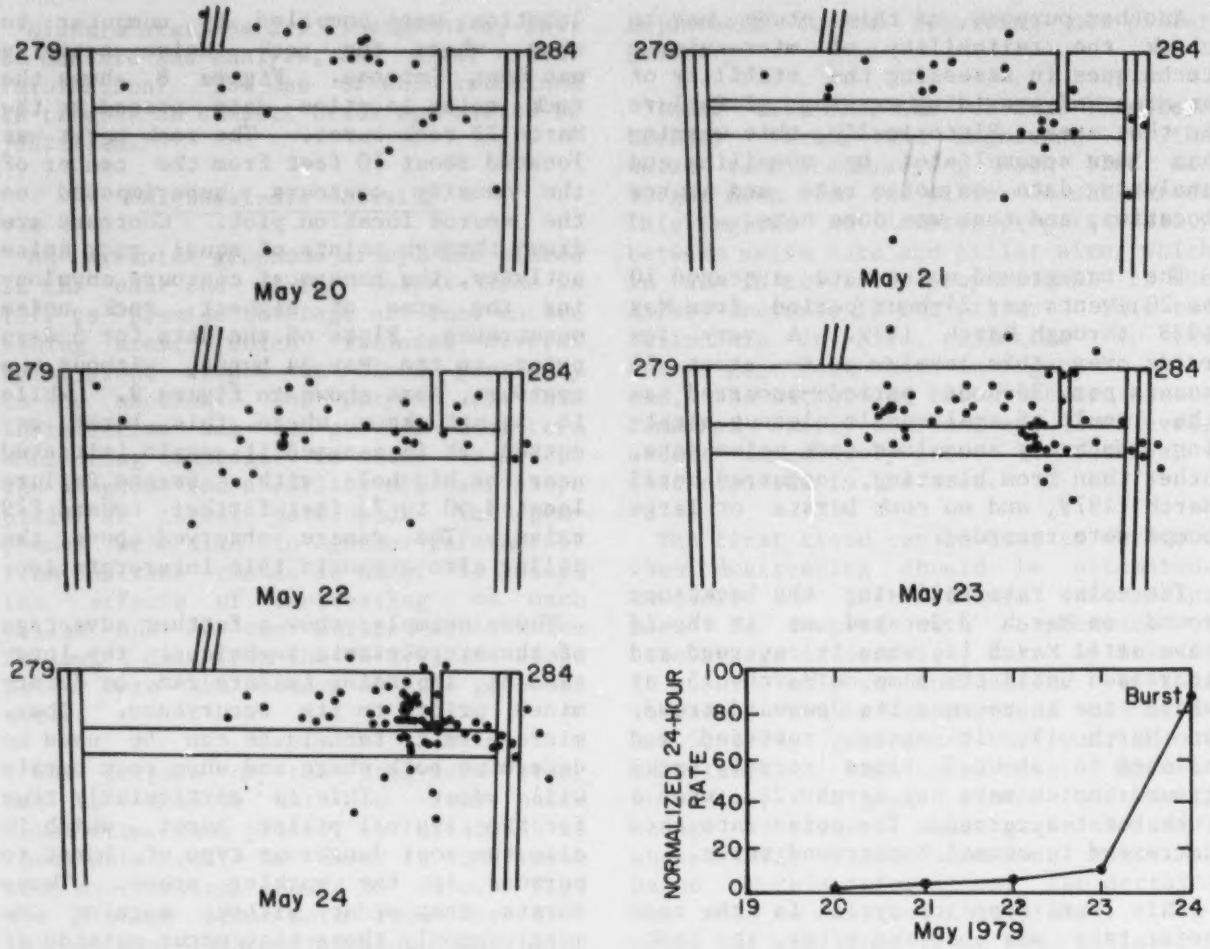

FIGURE 9. - Rock noise locations and rock noise rates preceding May 24, 1979, burst.

SUMMARY OF PILLAR REACTIONS

The condition of the pillar and its stability characteristics can be inferred at any point in time by examining pillar reactions as shown in the stress-change, closure, and rock noise data. In summary, the pillar in this study behaved as follows.

The period from May 1, 1978, through November 2, 1978, was characterized by very low background rock noise rates and very small changes in the stresses in the pillar. The only exceptions to this were short-term changes caused by blasting in the pillar. No closure data were recorded during this time.

The November 2, 1978, backstope blasting sequence reduced the pillar to a 48-foot depth. Historically, in this mine, rock burst problems do not usually occur until the pillar is about 40 feet thick. However, in this instance, the rock noise was uncharacteristically high, and the stresses increased at all locations within the pillar, with a very large increase on the 284 raise side of the stope, about 13 feet up from the stope opening. This was considered abnormal behavior and indicative of the need to destress the pillar, which was attempted but could not be accomplished.

From November 1978 until the backstope blast sequence of March, the stresses increased at a higher rate than previously observed on the 284 raise side of the pillar, and small-scale cleanup blasting in the stope produced unusually high rock noise rates in the area. This type of behavior is often observed as a stope pillar becomes highly stressed and its stability becomes questionable. The backstope round of March 9, 1979, produced another increase in the magnitude of the rock noise rate accompanying the blasting. The stresses were seen to increase sharply again on the 284 raise side of the pillar. Data from the displacement array showed this side of the pillar to be "stiff," compared with the central portion of the pillar, where the closure distribution was more uniform. Hence, the pillar was unstable at this time, particularly on the 284 raise side, as evidenced by data from all three monitoring networks.

The burst that occurred in this area on March 22, 1979, resulted in a large closure value in the drift above, which was interpreted to indicate that that portion of the pillar had been "softened" by the burst. The stress outside the pillar began a slow but steady increase, indicating a transferral of load from the pillar to the unmined area of the mine structure on the 284 raise end of the stope. However, the closure network also showed that the part of the pillar from the center to the 284 raise side had "softened" less than the surrounding areas. The microseismic activity in this area was also more intense than in other parts of the pillar. This indicated a relatively "stiff" area, a potential problem area in the pillar.

The backstope blast of May 11, 1979, generated an extremely high rock noise rate and a small but sudden shift of stress to the structure outside the mining area. The "stiff" portion of the pillar was still evident in the closure data and the microseismic data. The May 24, 1979, burst in that area caused more closure, but the area still could be interpreted as being "stiff." The locations of rock noise sources again showed this area to be the only active area in the pillar, though at a reduced level. No further bursts occurred there throughout mining.

CONCLUSIONS

The stress-change, closure, and microseismic monitoring systems used in this study of a rock-burst-prone stope pillar all served, to a greater or lesser degree, to reflect the reactions of the pillar during mining and rock bursting.

The VWSM technique of measuring stress changes at points within the pillar can yield useful information, in that the stress changes preceding rock bursts are discernable, if the gages are properly positioned in the structure. In this study, the gages seemed to be effective if they were located within about 20 feet of the burst area, a range most probably dictated by the characteristics of the stress distribution around the failure area. Hence, this technique is most useful when either a large number of gages can be deployed or some preknowledge allows placement of the gages in strategic locations. The technique is recommended for general stress studies where use of the VWSM gages is rigidly defined, and for use in monitoring small areas where stability problems are likely.

The closure network of extensometer pins proved to be simple and inexpensive. Closure data provided some basic information on which portions of the pillar behaved normally and which portions behaved abnormally. The method is somewhat limited in use because the array must be placed near (that is, in the openings around) rather than in the pillar; thus, only deflections peripheral to the pillar can be measured. Also, the method is best at assessing the condition of the pillar after bursting, as opposed to providing information before failure. The closure technique would therefore be

useful for estimating the effectiveness of destressing procedures. Because of the ease of its use and its cost effectiveness, this technique could easily be used to supplement the information available from microseismic monitoring of destressing attempts.

The microseismic technique performed well using historically established monitoring and analysis methods. Potential problem areas were well delineated by locating the sources of rock noise, and stability analyses were made by measuring rock noise rates. This was accomplished with state-of-the-art technology; the only new feature was that all data were manipulated by computer in real time, allowing assessments to be up-to-date and useful in terms of safety to mine personnel. A major advantage of microseismic techniques is that they can be used to assess not only a specific study area but the surrounding area as well. From this viewpoint, the technique is superior to most monitoring methods, which are restricted to use in the immediate area in which they are placed. Microseismic data can be used to determine when destressing techniques should be applied to a burst-prone pillar, and previous experience has shown that the data can be interpreted to evaluate the effectiveness of individual destressing attempts. This method of monitoring the stability of rock structures is therefore highly recommended at the current level of technology, and ongoing research promises to improve its reliability and ease of implementation.

REFERENCES

1. Blake, W. Rock Burst Mechanics. Quart. Colo. School Mines, v. 67, No. 1, 1972, 64 pp.

2. _____. Rock Burst Research at the Galena Mine, Wallace, Idaho. BuMines TPR 39, 1971, 22 pp.

3. Blake, W., and F. Leighton. Recent Developments and Applications of the Microseismic Method in Deep Mines. Ch. in Rock Mechanics--Theory and Practice (Proc. 11th Symp. on Rock Mechanics), ed. by W. H. Somerton. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, 1970, pp. 429-443.

4. Blake, W., F. Leighton, and W. I. Duvall. Microseismic Techniques for Monitoring the Behavior of Rock Structures. BuMines Bull. 665, 1974, 65 pp.

5. Langstaff, J. Hecla's Rock Burst Monitoring System. Min. Cong. J., v. 63, January 1977, pp. 46-52.

6. Leighton, F. Rock Burst Research at the Galena Mine, 1976. BuMines Denver Research Center Progress Rept. 10010, 1976, 23 pp.; available upon request from Research Director, Denver Research Center, Bureau of Mines, Denver, Colo.

7. Leighton, F., and W. Blake. Rock Noise Source Location Techniques. BuMines RI 7432, 1970, 18 pp.

8. Leighton, F., and W. I. Duvall. A Least Squares Method for Improving Rock Noise Source Location Techniques. BuMines RI 7626, 1972, 19 pp.

9. Rowell, G., and L. Yoder. The Effect of Geophone Emplacement on the Observed Frequency Content of Microseismic Signals. Paper in Proc. 3d Conf. on Acoustic Emission/Microseismic Activity in Geologic Structures and Materials, ed. by H. R. Hardy and F. Leighton. Trans Tech Publications, Rockport, Maine, 21 pp., in press; for information, contact F. Leighton, Bureau of Mines, Denver, Colo.

INT.-BU.OF MINES,PGH.,PA. 26301